- It does not take into account variations occurring after manufacturing. These variations can be very significant as a consequence of component drift, ageing and temperature variations.
- Manual calibration can be very time consuming and thus costly requiring special test setup and measurement circuitry.
- The calibration must be maintained throughout the lifetime of the product either by storing calibration values in non-volatile memory or by setting of adjustable components (such as a variable resistor or potentiometer), thus requiring additional components.

One system of calibration is described in US 6 272 322. In this system a pair of receivers perform a loop back test to determine a relationship between the transmit and receive gain for each transceiver. A path loss between the first transceiver and the second transceiver is computed by transmitting a pair of signals in opposite directions to determine the relationship between the transmit gain of one receiver and the receive gain of the second receiver. The individual transmit gain and receive gain is calculated from this relationship. The system described is relatively complex and specifically requires two transceivers operable to communicate with each other.

Thus an improved system of calibration would be advantageous.

**Summary of the Invention**

Accordingly the Invention seeks to provide a system of calibration of a transceiver mitigating one or more of the above mentioned disadvantages of the prior art.

Accordingly there is provided a method of gain calibration for a transceiver having a transmitter unit and a receiver unit and including a feed back coupling from the transmitter unit to the receiver unit, the feed back coupling comprising a measurement point; the method comprising the steps of: setting a reference signal level of a feedback signal at the measurement point by adjusting characteristics of the transmitter unit in response to a signal level detector measurement by a signal level

amplified in an amplifier 117 and up-converted to the transmit frequency by a second mixer 121. The up-converted signal is amplified by a first amplifier 123 having a variable gain, and after a second bandpass filter 125 by a transmit power amplifier 127. The power amplifier is connected to the antenna 129 through a transmitter switch 131.

A receiver unit of the transceiver comprises an input band pass filter 133 (BPF) for removing signal components outside the desired frequency band, and in particular the mirror frequency associated with subsequent down conversion. The band pass filter 133 is connected to the antenna 129 through a receiver switch 135 Typically both the receiver unit and the transmitter unit are coupled to the same antenna 129 through a duplexer (not shown). The filtered antenna signal is fed from the band pass filter 133 to a low noise amplifier 135 (LNA), which amplifies the received signal. The low noise amplifier 135 is designed with a very low noise figure and amplifies the signal to a level, at which the noise introduced in later stages of the receive process is low in comparison to the signal level. Therefore, the noise of the later stages does not significantly impact the receiver performance. The signal from the low noise amplifier is down-converted to an intermediate frequency (IF) in the mixer 139 and the down-converted signal is filtered in a second band-pass filter 141 which typically has a steeper frequency response than the input band-pass filter 133. Typically, the second band pass filter 141 determines the frequency response of the receive path in and around the required frequency band. Specifically, the bandwidth of the second band pass filter may be equal to a communication channel bandwidth rather than the bandwidth of the entire frequency band. Selection of the appropriate channel is performed by control of the down-conversion frequency.

The band pass filtered signal is amplified in an IF amplifier 143 having a variable gain before being down-converted to In-phase (I) and Quadrature (Q) channels by multiplication in mixers 145, 147 of the signal with local oscillator signals with 90 degree phase offset. Each of the I and Q base band signals is fed to an Analog to Digital Converter 157, 159 (ADC) through an ADC switch 153, 155. The digitised complex base band signal is fed to a Fast Fourier Transform and OFDM demodulator 161, which demodulates the signal to retrieve the data, as is well known in the art. In addition, the ADCs 157, 159 are connected to a digital signal level measurement unit

that generates a measure related to the signal level of the received signal. In one embodiment, the signal level measurement unit is a simple power level measurement unit performing the operation of

$$P = \alpha \cdot \sum_{N} i_n^2 + q_n^2$$

where α is a proportionality constant, $i_n$ is the n'th sample in the I-channel, $q_n$ is the n'th sample in the Q-channel and N is the length of an averaging window applied to the measurement.

Alternatively, the signal level measurement unit 163 may consist in any functionality that provides a measure related to the signal level of the received signal, including an amplitude level measurement. Preferably, the measure generated by the signal level measurement unit 163 is monotonically increasing with increasing signal level.

In accordance with a preferred embodiment of the invention, the transceiver comprises a feed back coupling between the transmitter and the receiver unit. In FIG. 1 this function is formed by the transmitter switch 131 and receiver switch 135 when in the lower switch position, as well as an attenuator 163. The attenuator shown in FIG. 1 simply comprises two resistors R2 and R3 in a known voltage divider configuration. Alternatively, the feedback coupling may comprise any suitable attenuator, may not comprise an attenuator and/or may include any other circuitry allowing a feed back coupling from the transmitter unit to the receiver unit to exist. The feed back coupling further comprises a measurement point 165, which in the specific embodiment of FIG. 1 is the point between the transmitter switch 131 and the attenuator 163.

The transmitter switch 131 is operable to switch between an upper position, in which the transmitter unit is coupled to the antenna 129, and a lower position in which the transmitter is coupled to the feedback coupling and the measurement point 165. Similarly, the receiver switch 135 is operable to switch between an upper position in which the receiver unit is connected to the antenna 129, and a lower position in which the receiver unit is coupled to the feedback coupling and, thus, through the attenuator 163 to the measurement point 165.

In some embodiments, the feed back coupling is permanently enabled, and the transceiver does not comprise switches for coupling the transceiver units between an antenna and the feed back coupling. In these embodiments, additional circuitry may be included for combining the feed back signals with the received signals. In one specific embodiment, the calibration is performed by a pure sine wave at a given frequency, and the calibration signal is isolated in the receiver by filtering. It is within the contemplation of the invention, that any suitable method and circuitry for forming a feed back coupling may be used, as well as any suitable method and circuitry for interfacing this with the receiver and transmitter units.

Further, a signal level detector 167 is connected to the measurement point 165. The output of the signal detector is in the described embodiment connected to a level adapter 169, the output of which is connected to the ADCs 157, 159 through the ADC switches 153, 155. The two ADC switches 153, 155 are each operable to switch between an upper position wherein the I and Q ADC 157, 159 is connected to the low pass filters 149, 151 of the receive path, and a lower position wherein the ADC 157, 159 of each switch is connected to the output of the level adapter 169. In this position, the ADC 157, 159 is thus fed the signal from the output of the signal level detector 167 as modified by the level adapter 169. The level adapter 169 is optional and simply provides the function of adjusting the level of the signal at the output of the signal level detector 167 to a level appropriate for the ADCs 157, 159. In the preferred embodiment, the level adapter 169 comprises a standard operational amplifier coupled to provide a suitable static gain (typically less than one). In other embodiments, the level adapter may attenuate the signal level and/or be adjusted in response to the signal level at the output of the signal level indicator 167. In the preferred embodiment, the output of the level adapter 169 is coupled to both ADC switches 153, 155 and thus to both ADCs 161, 163. In other embodiments, the output of the level adapter 169 may only be connected to one switch. In some embodiments, no switches are employed, and the signal from the level adapter is coupled to the signal level measurement unit 163 through other suitable means, such as for example through an additional dedicated ADC.

The signal level detector 167 is preferably a power detector. In the preferred embodiment, the signal level detector 167 is a simple amplitude peak detector comprising a resistor R1, a diode C and a capacitor C as is well known in the art. The value of the capacitor C is set such that it, together with the input impedance of the level adapter 169, provides a suitable dynamic performance of the peak detector. The dynamic performance is preferably such that signal level variations are filtered while changes in the signal level at the measurement point 167 are measured sufficiently fast. Alternatively, the power detector may comprise a second resistor in parallel with the capacitor. If the second resistor is significantly less than the input impedance of the level adapter, the time constant of the peak detector, and thus the dynamic performance, can be determined by the capacitor value and the resistance of the second resistor.

FIG. 2 shows a flow chart 200 for a method of calibration in accordance with an embodiment of the invention. The method will be described with reference to the transceiver of FIG. 1

In step 201, a reference signal level of a feedback signal at the measurement point 165 is set by adjusting characteristics of the transmitter unit in response to a signal level detector measurement by the signal level measurement unit 163 when coupled to the measurement point 165 through the signal level detector 167.

Initially, the transmitter switch 131 and the ADC switches 157, 159 are switched to the lower switch position whereby a path is formed from the transmitter output to the signal level measurement unit 163 through the transmit switch 131, measurement point 165, signal level detector 167, level adapter 169, ADC switches 153, 155 and ADCs 157,159. Thus the signal level measurement unit 163 is coupled such that it can measure the signal level, and in the preferred embodiment, the power level of the feed back signal at the measurement point 165. The feed back signal is generated in the transmitter, and in the preferred embodiment a constant amplitude sine wave with a frequency in the transmit frequency band is used as a dedicated calibration signal. The calibration signal is generated by the digital OFDM modulator 101. The signal level of the feedback signal can be adjusted in various ways, including adjusting the amplitude of the generated digital calibration signal or adjusting a gain of a first

In step 203, a measurement reference value associated with the reference signal level is measured by the measurement unit when coupled to the measurement unit through the receiver unit.

In this step, the ADC switches 153, 155 are switched from the lower position to the upper position and the receiver switch is set at the lower position. Consequently, the signal level measurement unit 163 is coupled to the measurement point 165 through the attenuator 163, the receiver path, the ADC switches 153, 155 and the ADCs 157, 159. The characteristics of the transmitter are not changed and thus the signal level measurement unit 163 is now measuring a measurement reference value which corresponds to measuring the reference signal level through the receiver unit.

In step 205, a gain parameter of a transceiver unit of the transceiver is changed by a gain step. In the preferred embodiment, either a gain associated with the transmitter unit, such as the gain of the first amplifier 123, or a gain associated with the receiver unit, such as the gain of the IF amplifier 143, is changed. The gain step may be of any suitable size, and in one embodiment the gain step is infinitesimal such that repeating the calibration with additional gain steps corresponds to a continuous variation of a gain associated with the transceiver unit over a gain range.

Step 207 comprises measuring, by the measurement unit when coupled to the measurement unit through the receiver unit, at least one measurement of a feedback signal level of the feedback signal.

As a consequence of the gain step, the signal level measured by the signal level measurement unit 163 will have changed. If the gain step is of the transmitter, the signal level of the feed back signal has changed, and thus the measurement will change as the receiver path and signal level measurement unit 163 is unchanged. If the gain step is of the receiver, the signal level of the feedback signal is unchanged but as the gain of the receiver path has changed, the signal level at the ADCs will have changed, and thus the measurement by the signal level measurement unit 163 will change.

gain of the first amplifier may be increased until the signal level is above the reference signal level, at which point the gain is reduced one step and the signal level of the calibration signal is gradually increased until the correct level is reached.

Following the accurate calibration of the absolute level of the transmit gain $G_{T,Ref}$, the ADC switches 157, 159 are changed to the upper position thereby connecting the signal level measurement unit 163 to the measurement point 165 through the receiver path. The signal level of the feedback signal is still at the reference signal level, and the measurement of the signal level measurement unit 163 corresponding to this level is stored as a measurement reference level.

A gain step of the transmit path is then performed by adjusting the gain of the first power amplifier by a step. In the preferred embodiment, the gain of the first amplifier 123 is controlled by digital control signals and the step size is equal to the lowest step possible, i.e. equal to a quantisation step for the gain of the first amplifier 123. Following the gains step and after allowing sufficient time for the system to settle, a measurement is made by the signal level measurement unit 163. In the preferred embodiment, the gain of the first amplifier 123 is initially reduced by one setting and consequently the signal level measurement by the signal level measurement unit 163 will be lower than the reference measurement value.

A relative effect on the signal level of the feedback signal is determined as a change in the measurement of the signal level measurement unit 163 and specifically as the difference between the new measurement value and the measurement reference value. The gain step is then calibrated as the difference between the measurement values. Thus the calibrated gain of the gain step is determined as

$$\Delta G(-1) = P(-1) - P_{Meas,\mathrm{Ref}}$$

where $\Delta G(-1)$ is the relative value of the gains step in dB (and is negative for a reduction in gain), $P_{Meas,Ref}$ is the measurement reference value in dBm and P(-1) is the measured value of the signal level measurement unit following the gain step.

The calibration is then continued in a similar fashion until all gain settings of the desired dynamic range have been covered.

In the preferred embodiment both the transmitter unit and the receiver unit is calibrated. When calibrating the receiver unit, the reference signal level is initially set as described for the transmitter calibration. The ADC switches are then switched to the upper position thereby connecting the signal level measurement unit 163 to the measurement point through the receiver path. The signal level of the feedback signal is at the reference signal level, and the signal level measurement unit is measuring a value corresponding to the measurement reference value. In the preferred embodiment, a calibration of an absolute gain of the receiver path is performed. Preferably, the receiver absolute gain calibration is performed immediately after the calibration of the transmitter unit's absolute gain and before the calibration of the entire dynamic gain range of the transmitter unit.

The calibration of the absolute gain of the receiver is preferably in response to the measurement reference value and the reference signal level. The attenuation of the attenuator 163 is known and thus the signal level at the input level of the receiver is known. The measurement reference value is a measure of the signal level at the ADCs, and thus the gain of the receive path can be calculated as the ratio between the input signal level and the signal level at the ADCs.

Specifically, the calibration of the absolute gain value of the receiver is performed by initially setting the gain of the receiver path to the minimum value. The reference signal level is set for the feedback signal, and the signal level measurement unit is coupled to the measurement point through the receiver path. The reference signal level and the attenuator ratio are preferably set such that the receiver input signal level corresponds to the upper threshold for the dynamic range of the receiver. The gain of the receiver is stepped up until the ADCs are overloaded. The gain of the receiver path is reduced by one step whereby the signal at the ADC input is brought back within range. The input signal level for the receiver is now at the maximum level and the signal level measurement unit indicates a power close to full scale. The signal level measurement unit 163 performs a measurement of the signal level and the

Claims

1. A method of gain calibration for a transceiver having a transmitter unit and a receiver unit and including a feed back coupling from the transmitter unit to the receiver unit, the feed back coupling comprising a measurement point; the method comprising the steps of:

setting a reference signal level of a feedback signal at the measurement point by adjusting characteristics of the transmitter unit in response to a signal level detector measurement by a signal level measurement unit when coupled to the measurement point through a signal level detector;

measuring, by the measurement unit when coupled to the measurement unit through the receiver unit, a measurement reference value associated with the reference signal level;

changing a gain parameter of a transceiver unit of the transceiver by a gain step;

measuring , by the measurement unit when coupled to the measurement unit through the receiver unit, at least one measurement of a feedback signal level of the feedback signal;

determining a relative effect of the gain step on the feedback signal level in response to the at least one measurement relative to the measurement reference value; and

calibrating the gain step in response to the relative effect of the gain step on the feedback signal.

2. A method as claimed in claim 1 wherein the relative effect is determined as a relative change of the at least one measurement with respect to the measurement reference value.

3. A method as claimed in claim 2 wherein the relative effect is determined as the difference between the at least one measurement and the measurement reference value.

4. A method as claimed in claim 1 wherein the relative effect is determined as a relative change in the feedback signal level required to achieve a predefined

relationship between the at least one measurement and the measurement reference value.

5. A method as claimed in claim 4 wherein the predefined relationship is that the at least one measurement is substantially equal to the measurement reference value.

6. A method as claimed in claim 4 or 5 wherein the step of calibrating the gain step comprises determining the gain step as substantially being the same value as the relative effect.

7. A method as claimed in any previous claim, wherein the transmitter comprises a signal generator coupled to the feed back coupling through a transmit path having a transmit path gain and further comprising the step of:

setting a known level at the signal generator;

adjusting the transmit path gain until the measurement unit, when connected to the measurement point through the signal level detector, measures a level equal to the measurement reference value; and

calibrating an absolute value of the transmit path gain as a function of the known signal level and a predetermined relationship between the reference signal level and a measurement value of the measurement unit when connected to the measurement point through the signal level detector.

8. A method as claimed in any previous claim wherein the receiver comprises a receive path having a receive path gain and further comprising the step of calibrating an absolute value of the receive path gain in response to the measurement reference value and the reference signal level.

9. A method as claimed in any of the previous claims wherein the transceiver unit is the transmitter unit having a transmit path having a transmit path gain and the gain step is a gain step of the transmit path gain.

10. A method as claimed in claim 9 wherein the transmitter unit comprises a digital signal generator for generating a calibration signal coupled to the measurement point through the transmit path, the transmit path being an analog transmit path.

18. A method as claimed in claim 17 wherein the step of determining the relative effect is further in response to the relative effect determined in previous iterations.

19. A method as claimed in any previous claim wherein the signal level detector has a limited dynamic input range of low distortion, and the reference signal level is set to fall within this dynamic range.

20. A method as claimed in any previous claim further comprising the step of pre-calibrating a measurement of the measurement unit when measuring the reference signal level through the signal level detector.

21. An apparatus for gain calibration for a transceiver having a transmitter unit and a receiver unit and including a feed back coupling from the transmitter unit to the receiver unit, the feed back coupling comprising a measurement point; the apparatus comprising:

a signal level measurement unit for measuring signal levels related to a feedback signal at the measurement point; the signal level measurement unit operable to be coupled to the measurement point through the receiver unit and/or through a signal level detector;

means for setting a reference signal level of the feedback signal at the measurement point by adjusting characteristics of the transmitter unit in response to a signal level detector measurement by the signal level measurement unit when coupled to the measurement point through the signal level detector;

means for controlling the measurement unit, when coupled to the measurement unit through the receiver unit, to perform a measurement reference value associated with the reference signal level;

means for changing a gain parameter of a transceiver unit of the transceiver by a gain step;

means for controlling the measurement unit, when coupled to the measurement unit through the receiver unit, to perform at least one measurement of a feedback signal level of the feedback signal;

means for determining a relative effect of the gain step on the feedback signal level in response to the at least one measurement relative to the measurement reference value; and

means for calibrating the gain step in response to the relative effect of the gain step on the feedback signal.

22. An apparatus as claimed in claim 21 wherein the means for determining a relative effect is operable to determine the relative effect as a relative change of the at least one measurement with respect to the measurement reference value.

23. An apparatus as claimed in claim 22 wherein the means for determining a relative effect is operable to determine the relative effect as the difference between the at least one measurement and the measurement reference value.

24. An apparatus as claimed in claim 21 wherein the means for determining a relative effect is operable to determine the relative effect as a relative change in the feedback signal level required to achieve a predefined relationship between the at least one measurement and the measurement reference value.

25. An apparatus as claimed in claim 24 wherein the predefined relationship is that the at least one measurement is substantially equal to the measurement reference value.

26. An apparatus as claimed in claim 24 or 25 wherein the means for calibrating the gain step is operable to determine the gain step as substantially being the same value as the relative effect.

27. An apparatus as claimed in any of the previous claims 21 to 26 further comprising:

a signal generator coupled to the feed back coupling through a transmit path having a transmit path gain;

means for setting a known level at the signal generator;

means for adjusting the transmit path gain until the measurement unit, when connected to the measurement point through the signal level detector, measures a level equal to the measurement reference value; and

means for calibrating an absolute value of the transmit path gain as a function of the known signal level, and a predetermined relationship between the reference

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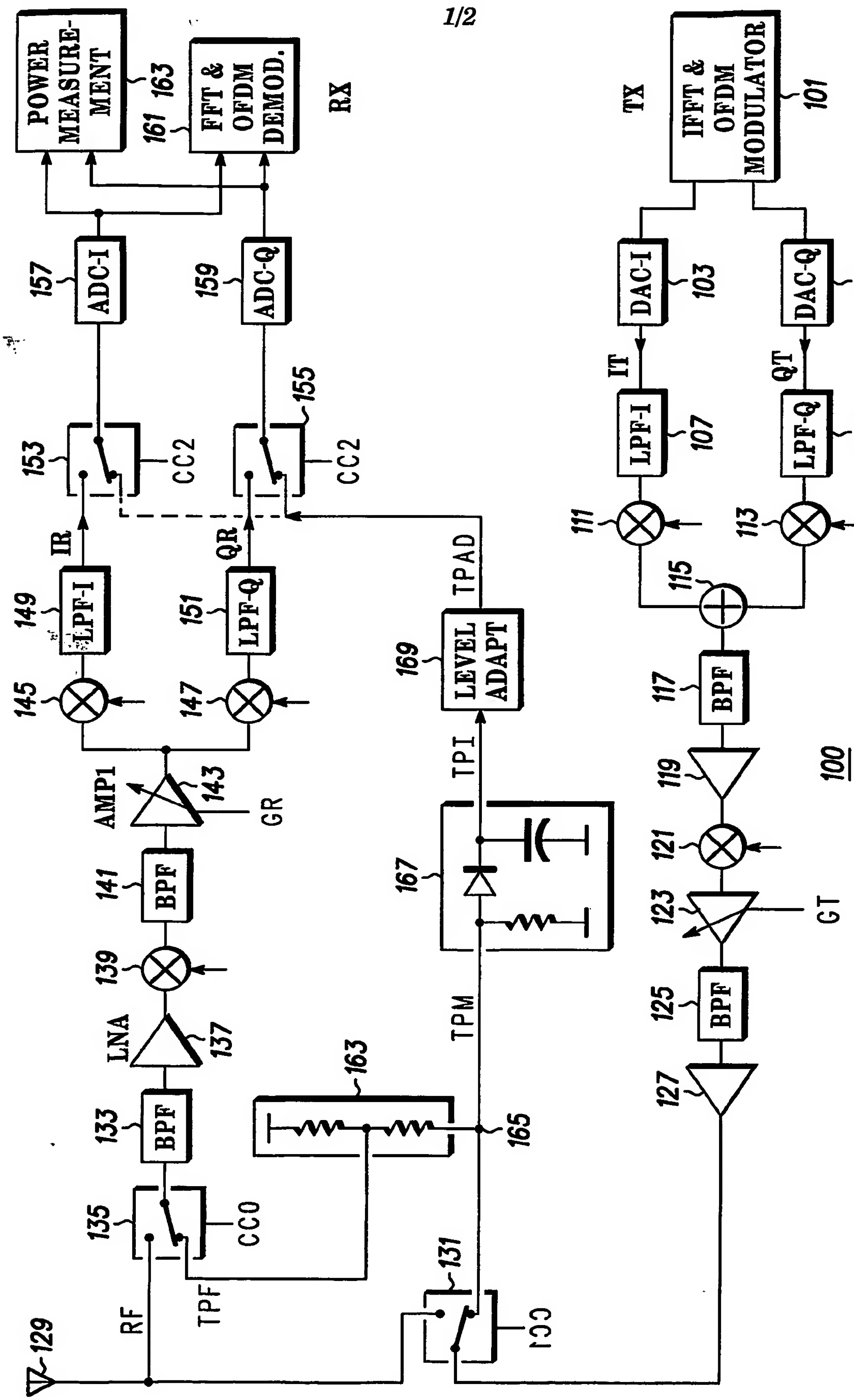


FIG. 1

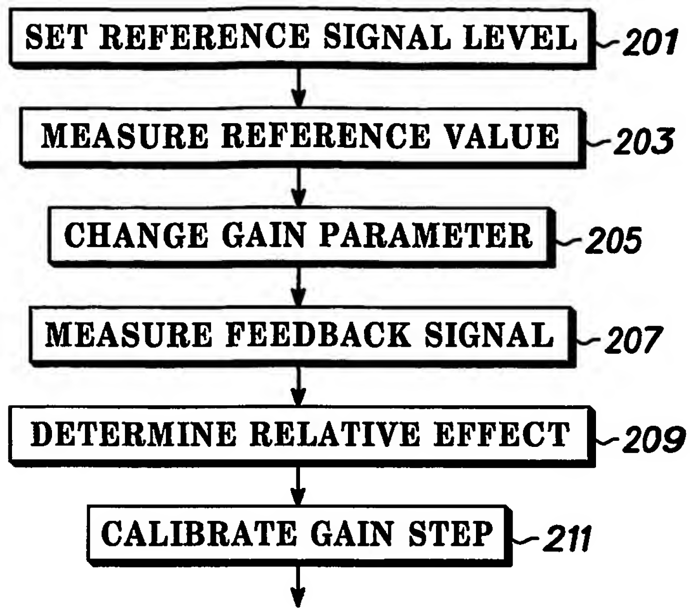
SET REFERENCE SIGNAL LEVEL
201
MEASURE REFERENCE VALUE
203
CHANGE GAIN PARAMETER
205
MEASURE FEEDBACK SIGNAL
207
DETERMINE RELATIVE EFFECT
209
CALIBRATE GAIN STEP
211

*FIG. 2* 201